Plant Vintage, Technology, and Environmental Regulation

Wayne B. Gray
Clark University and NBER

and

Ronald J. Shadbegian
University of Massachusetts at Dartmouth and
U.S.E.P.A., National Center for Environmental Economics

Financial support for the research from the National Science Foundation (grant # SBR-9410059) and the Environmental Protection Agency (grant #R-826155-01-0) is gratefully acknowledged, as is access to Census data at the Boston Research Data Center. We are also grateful to the many people in the paper industry who were willing to share their knowledge of the industry with us. Capable research assistance was provided by Zahid Hafeez. The opinions and conclusions expressed are those of the author and not the Census Bureau, EPA, or NSF. All papers are screened to ensure that they do not disclose confidential information. Any remaining errors or omissions are the authors'.

Abstract

Does the impact of environmental regulation differ by plant vintage and technology? We answer this question using annual Census Bureau information on 116 pulp and paper mills' vintage, technology, productivity, and pollution abatement operating costs for 1979-1990.

We find a significant negative relationship between pollution abatement costs and productivity levels. This is due almost entirely to integrated mills (those incorporating a pulping process), where a one standard deviation increase in abatement costs is predicted to reduce productivity by 5.4 percent. Older plants appear to have lower productivity but are less sensitive to abatement costs, perhaps due to 'grandfathering' of regulations. Mills which undergo renovations are also less sensitive to abatement costs, although these vintage and renovation results are not generally significant. We find similar results using a log-linear version of a three input Cobb-Douglas production function in which we include our technology, vintage, and renovation variables.

Sample calculations of the impact of pollution abatement on productivity show the importance of allowing for differences based on plant technology. In a model incorporating technology interactions we estimate that total pollution abatement costs reduce productivity levels by an average of 4.7 percent across all the plants. The comparable estimate without technology interactions is 3.3 percent, approximately 30% lower.

Wayne B. Gray
Economics Department
Clark University
950 Main Street
Worcester, MA 01610
and NBER
wgray@clarku.edu

Ronald J. Shadbegian
Economics Department
University of Massachusetts at Dartmouth
285 Old Westport Road
North Dartmouth, MA 02747
rshadbegian@umassd.edu

1. Introduction

Does the impact of environmental regulation differ by plant vintage and technology? In other words, can plants of different ages and which employ different technologies more easily comply with environmental regulation than others? To answer this question we use annual Census Bureau information on 116 pulp and paper mill's vintage, technology, productivity, and pollution abatement operating costs over the time period 1979-1990.

Previous research on the impact of environmental regulation on productivity can be split into two groups: growth accounting studies and econometric studies. Growth accounting studies use estimates of compliance costs to calculate productivity effects (see Dension [1979]) and typically find only a small impact on productivity because compliance costs are a small share of total costs. On the other hand, econometric studies like Gollop and Roberts (1983) use plant-level data, and Gray (1986,1987) and Barbera and McConnell (1986) use industry-level data in a more formal multiple regression framework to test for regulation's impact on productivity. These econometric studies generally find significant negative impacts of regulation on productivity, although not always very large ones.

Our study builds upon earlier work by Gray and Shadbegian (1995) which finds a significant connection between pollution abatement costs and productivity at plants in the steel, oil, and paper industries. Gray and Shadbegian find a larger impact than would be expected in a simple growth accounting framework. In particular, at paper mills, $1.00 of abatement costs translated into the equivalent of $1.80 or more in lower productivity. For oil the estimated impacts were smaller than those for paper, $1.40; for steel they were larger, approximately $3.30, but more variable across specifications. These results suggest that estimates of the economic impact of regulation based on reported abatement costs may be understated. They also indicate that regulatory burdens differ across industries, not only because they face different abatement costs, but also because a given amount of abatement costs has different impacts across industries. Therefore, policy-makers should evaluate the impact of environmental regulation on an industry-by-industry basis, to avoid substantial under- (or over-) estimates.

In this paper we take the analysis further, by looking at differences in the impact of environmental regulation across different plants within a single industry. We concentrate on the pulp and paper industry for a number of reasons. First, the industry is a major polluter, with both air and water pollution concerns, and it spends more on pollution abatement than most other manufacturing industries. Second, the plants in the industry operate a variety of production technologies, differing substantially in the pollution they generate. Finally, a significant and stable negative relationship between abatement costs and productivity was found by Gray and Shadbegian (1995), suggesting the possibility of finding significant differences across paper mills of different vintages and technologies.

Using a Census Bureau panel dataset on 116 pulp and paper mills, we find a significant negative relationship between pollution abatement costs and productivity levels, which is almost entirely due to mills which incorporate a pulping process -- these mills are referred to 'integrated mills'. Since integrated mills also have higher abatement costs (twice as large as their non-pulping counterparts), the predicted impact of regulation on productivity for integrated mills is especially large. For example, a one standard deviation increase in abatement costs at an integrated mill is predicted to reduce its productivity level by 5.4 percent. The results for vintage are generally not significant, with some indication that older plants have lower productivity but are slightly less sensitive to abatement costs, perhaps due to 'grandfathering' of regulations. Lastly, mills which have recently undergone a large renovation are less sensitive to abatement costs, although these results are also not generally significant.

We also examine the impact of abatement costs using a production function model. We estimate a log-linear version of a three input Cobb-Douglas production function in which we include our technology, vintage, and renovation variables. The results for PAOC and its interactions with technology, vintage, and renovation are similar to those found in the earlier tables: controlling for the contributions of inputs, output is lower in plants with greater abatement costs, with nearly all of this impact concentrated in integrated mills.

Sample calculations of the impact of pollution abatement on productivity show the importance of allowing for differences based on plant technology. In a model incorporating technology interactions we estimate that total pollution abatement costs reduced productivity by an average of 4.7 percent across all the plants. The comparable estimate without technology interactions is 3.3 percent, approximately 30% lower. Our results also suggest that increased regulatory stringency might affect industry structure, if higher abatement costs put integrated mills at a competitive disadvantage.

Section 2 describes paper industry technologies and how they are affected by regulation, along with a model of the impact of regulation on productivity. Section 3 describes the data used in the analyses. In Section 4 we present the results, with concluding remarks in Section 5.

2. Paper Industry Productivity and Environmental Regulation

Over the past thirty years, environmental standards in the U.S. have grown increasingly more stringent, with frequent changes in the level of pollution control required. Before 1970 environmental regulation was done primarily by state and local agencies -- for the most part without very serious enforcement mechanisms. With the establishment of the Environmental Protection Agency in the early 1970s, and the passage of the Clean Air and Clean Water Acts, the federal government took a lead role in regulation, imposing more stringent regulations with correspondingly stricter enforcement. Since the early 1970's, regulations have been tightened, with some shifts in emphasis from basic air and water quality in the 1970s to toxic chemicals in the 1980s.

Increased regulation has led to substantial increases in pollution abatement spending, nearly tripling from 0.3 percent of total manufacturing shipments in 1973 to 1 percent in 1993. However existing productivity measures do not distinguish between abatement spending and other production costs, thus they will tend to reduce 'measured' productivity. Productivity is a ratio of output to inputs, so if one plant has 2 percent higher costs due to pollution abatement, it would be expected to have 2 percent lower productivity (Gray 1987). This proportional mismeasurement is the basis for the analysis used in Gray and Shadbegian (1995) where a plant's productivity level is regressed on its abatement costs as a share of total cost -- the 'expected' coefficient on abatement costs is -1. A larger (more negative) coefficient would indicate that the abatement cost numbers understate the 'true' abatement costs for the plant.[1] If certain types of

[1] For this estimation to exactly capture the effects of mismeasurement, the unmeasured part of abatement costs needs to be proportional to the measured abatement costs.

plants have more complicated abatement problems, we might expect to find their productivity especially sensitive to their pollution abatement costs.

The paper-making process is a heavily polluting one, generating both air and water pollution. The first, and dirtiest, stage of the process is pulping, where some source of fiber (ranging from trees and wood chips to recycled cardboard or waste paper) is treated to separate out the fibers, bleached in some cases to increase whiteness, and mixed with water to form a slurry. In the second stage, this slurry (more than 90% water at the start) is deposited on a rapidly-moving wire mesh which then passes through a series of dryers to remove the water and create a continuous sheet of paper.

From the standpoint of environmental impact, the pulping stage provides most of the pollution, and most of the differences across plants. If the plant uses raw wood for input, the fibers must be separated from the lignin that binds them together; this can be done chemically, mechanically, or with various combinations of heat, pressure, and chemicals. If the plant uses recycled cardboard or paper, it is easier to separate the fibers, but there can be other waste material in the input stream, generating sizable amounts of sludge with its own disposal problems. The paper-making process has smaller pollution problems, with less variation across plants: air pollution associated with a power-generating boiler (needed to create steam for the dryers) and water pollution from residual fibers remaining in the water as the paper is dried. Therefore, we will focus on the distinction between integrated mills and non-pulping plants as the key technology difference across plants.

Over time, the paper industry has substantially reduced its pollution. Nearly all plants have installed secondary treatment of wastewater, reducing traditional forms of water pollutants.

Plants with boilers have generally installed electrostatic precipitators to reduce particulate emissions, and scrubbers to reduce sulfur dioxide emissions. In addition to these 'end-of-pipe' controls, the material flow through the plants has been more closely controlled, with fibers in the wastewater being recovered and reused, and exhaust gases from the pulping and bleaching stages being captured and treated. The recapture of fiber may provide a net economic benefit to the plant, in addition to the pollution reductions.

Once a plant is in operation, it is very difficult to change the production process. For example, older plants generally have problems with recapturing fiber from the waste stream (some early paper mills were built over water with holes in the floor so that spills could be 'conveniently' disposed of!). In any plant, changing the chemistry in one part of the process can change the capacity requirements in another area.[2] These problems, expected to be most serious in plants that were designed before environmental concerns were prominent, may be partially or completely offset by the tendency for regulations to include grandfather clauses which exempt existing plants from the most stringent regulations. For example, air pollution regulations apply stricter New Source Performance Standards only to new or substantially renovated plants. Several authors have noted the possibility that such regulations may have perverse effects on total emissions, discouraging investment in newer capital, both in electric power generation and automobiles.

Based on the above discussion, we would expect plants that incorporate some pulping

[2] For example, installing oxygen delignification (reducing the need for chlorine bleaching) in one plant would increase the flow of waste material to a recovery boiler by 3 percent. Because the recovery boiler was designed to match the capacity of the rest of the process, the plant would either need to spend tens of millions of dollars for a new recovery boiler, or accept a 3 percent reduction in pulp production.

process starting with raw wood to have higher abatement costs than plants with only the paper-making part of the process -- this might or might not translate into a larger impact per dollar of abatement costs. We also expect older plants to be less productive -- they might have more difficulty meeting a given standard, leading to higher abatement costs, but grandfathering could reduce or eliminate this difference.

To describe the model more formally, let TFP_{it} and $PAOC_{it}$ represent the total factor productivity level and pollution abatement spending level in plant i at time t, with technology and vintage variables X_i:

$$(1) TFP_{it} = \alpha_i + \beta PAOC_{it} + \sum_k \gamma_{xk} X_{ik} + \sum_k \delta_{xk} X_{ik} PAOC_{it} + \lambda_t + \varepsilon_{it} .$$

The X variables in this equation are all dummies, and the lack of a time subscript reflects their inherently cross-sectional nature. Equation (1) is estimated in both levels and first-differences, where first-differencing controls for the plant-specific fixed effects (α_i). All models include time effects (λ_t). The technology and vintage X variables are fixed, therefore they drop out of the first-differenced estimations, but the X*PAOC terms remain; this allows for different impacts of PAOC on productivity for each technology or vintage group. A negative γ coefficient indicates a technology (or vintage) with lower productivity. A negative δ coefficient indicates a technology (or vintage) whose productivity is more sensitive to abatement costs, or for which abatement costs are especially understated.[3]

[3] The symmetry between sensitivity and mismeasurement is really a matter of definition, since the same result (lower than expected output for plants facing higher pollution abatement efforts) would arise in each case.

The productivity levels TFP_{it} are the residuals from a three-input production function model, in which output levels are regressed on labor, capital, and materials inputs -- this specification is described more fully in Gray and Shadbegian (1995). Our productivity measures are similar to those that would be obtained from a growth accounting framework, calculating factor cost shares rather than estimating coefficients econometrically. The productivity regressions are done in log form, expressed relative to a base of 100, so a difference of 10 in TFP_{it} can be interpreted as a 10 percent difference in productivity levels.

An alternative method for testing the impact of pollution abatement costs on productivity comes through production function estimation. We use a simple Cobb-Douglas production function, comparable to the one used to calculate the productivity measure TFP in equation (1). Output (Q) is a function of three inputs (IP_j): labor, capital, and materials. The technology and vintage dummies (X_i) are still allowed to interact with PAOC.

$$(2) Q_{it} = \alpha_i + \beta PAOC_{it} + \sum_k \gamma_{xk} X_{ik} + \sum_k \delta_{xk} X_{ik} PAOC_{it} + \sum_j \phi_j IP_j + \lambda_t + \varepsilon_{it} .$$

Equation (2) is also estimated in both levels and first-differences.

3. Data and Econometric Issues

The basic data for the project comes from the Longitudinal Research Database (LRD) which contains information on manufacturing plants from the Census of Manufacturers and Annual Survey of Manufacturers linked together for individual plants over time (for a more detailed description of the LRD data, see McGuckin and Pascoe (1988)). Our data set consists of 116 pulp and paper plants with continuous data over the 1979-1990 period -- this data set provides the productivity measure (TFP) used in our basic analysis.[4]

We also use information from the LRD for the production function analysis. The value of shipments is adjusted for inventory changes and deflated by the industry price of shipments (using the paper industry deflator from Bartelsman and Gray [1996]) to measure a plant's output. Three inputs are used: labor, capital, and materials. Labor is measured in terms of worker hours, using production worker hours and assuming non-production workers work 2000 hours per year. Nominal materials and energy expenditures are divided by an industry price index to put them in real terms. A real capital stock measure is constructed from an examination of year-to-year variations in book value, incorporating data on new investment in the plant and retirements of existing capital.[5]

We combine this productivity data with other Census information. The Pollution Abatement Costs and Expenditures (PACE) survey, conducted annually by the Census Bureau, provides annual abatement cost data from 1979 to 1990.[6] We use a plant's pollution abatement operating costs divided by its shipments to summarize the plant's pollution abatement expenditures (PAOC).[7]

We use detailed information on plant output from the LRD to ascertain whether or not a

[4] The plants are classified in either SIC 2611 (pulp) or 2621 (paper), depending on which accounts for a larger part of the plant's shipments.

[5] For a detailed description of this technique see Doms (1996).

[6] No survey was done in 1987 for budget reasons, and we interpolate that year's data.

[7] To avoid year-to-year variation in shipments, we use the peak two years of shipments from the sample for the denominator. Some plants have a few years of missing data for pollution abatement costs, but these are interpolated, based on their values for surrounding years.

plant has pulping technology (PULP). LRD data on annual investment spending is used to create two capital-vintage variables: RENOV and OLD. RENOV is a 'recent major upgrade' dummy variable -- this is defined as having total new investment over a two-year period exceeding 80 percent of the plant's initial capital stock, and remains 'turned on' for three years after the investment. OLD is a dummy variable indicating if a plant opened before 1960.[8] We choose to present the results for a single dummy (OLD) for several reasons. First, our sample includes some very old plants, likely to heavily influence any linear (or non-linear) age specification. Second, concern with environmental issues was not prominent before the 1960s. Third, in earlier analyses we explored splitting OLD into three time period dummies. Each of the three periods had the same sign, as did their interactions with PAOC, though there was some variation across the three time periods' coefficients.[9]

We employ a variety of estimation methods, beginning in each case with ordinary least squares. We then estimate the model in first-differences, to control for plant-specific fixed effects. Estimation using first-differences is desirable on theoretical grounds, since this minimizes the possibility of unmeasured plant characteristics biasing the other coefficients. However, some of our coefficients of interest are purely cross-sectional, such as plant vintage, so they drop out of the first-differenced models. Other variables may have limited within-plant variation, providing little information for the first-differenced models to work with, and possibly exacerbating problems with measurement error. Another problem is the possibility of the

---

[8] We would like to thank John Haltiwanger who developed the plant age data based on LRD data.

[9] These results are available from the authors. Some of the individual age dummy coefficients may not be 'disclosable' (outside the Census Bureau), due to the Census Bureau's disclosure rules.

endogeneity of PAOC, either in terms of levels or first-differences. We are limited by the lack of clearly exogenous (and time-varying) instruments to explain differences in PAOC, so we use a Generalized Method of Moments (GMM) model suggested by Arellano and Bond (1991), which incorporates all possible lagged levels and differences of the endogenous variables to serve as instruments for the current values of the endogenous variables in the model.[10]

4. Estimation Results

Table 1 presents summary statistics for all the variables used in the analysis. Slightly less than half the plants in the sample have a pulping process (PULP). Almost all plants were opened before 1960 (OLD), with over a third of the observations falling within three years of a major renovation (RENOV). We also find sizable differences in pollution abatement spending between the different subgroups of plants. The largest difference is for PULP: plants with pulping facilities spend twice as much as those without pulping. Plants started before 1960 (OLD), or undergoing a recent renovation (RENOV) also have somewhat higher abatement cost spending (although the precise figures cannot be reported here due to Census Bureau disclosure rules). Abatement costs are expressed relative to the plant's shipments, therefore these PAOC differences are not simply due to differences in the scale of different types of plants.

Table 2 examines the relationship between productivity and the technology measure (PULP), using OLS and first-differenced estimates of equation (1). First, we see a strong pattern of year effects throughout the models. The coefficients appear different across the three sets of

[10] Other papers using this technique include Black and Lynch (1996), Arellano (1995), and Arrelano and Bover (1995).

models (OLS-levels, OLS-differences, and GMM-differences), but this reflects differences in specification and base years. The OLS-levels models (2a -2b) show that the highest levels of productivity were in 1983, 1985 and 1986, and the lowest levels in 1980, 1989, and 1990. Several years show large changes in coefficients between years, falling for 1979-1980, 1986-1987, and 1987-1988 and rising for 1982-1983 and 1984-1985. When we move to OLS-differences these changes in coefficients (from 2a-2b) become the coefficients themselves (in 2c-2d), and are all positive because the base difference, 1979-1980, is the largest negative value in the period. Finally, the GMM-differences model drops the first year of data in creating instruments, so the base difference is now 1980-1981, which is slightly positive, making the year dummy coefficients in models 2e-2f more negative than those in 2c-2d, though with similar relative coefficients. The year effects are consistent across all of the remaining tables, so they are omitted from later tables to save space.

We note that plants with higher abatement costs have lower productivity levels, for both the estimators. The impact is about –2.2, substantially larger than the expected -1.0 for the OLS model estimated in levels (2a). Going to first-differences in OLS reduces the coefficient to just under –1 (model 2c). When we move to a GMM specification of the first-differenced model, the coefficient returns to the higher level of the OLS-level specification (model 2e), suggesting that some of the drop in the PAOC coefficient in model 2c may have been due to endogeneity (and corrected for by the GMM instruments). Using the simplest OLS results, a one standard deviation (1.162) increase in PAOC (model 2a) is predicted to reduce a plant's productivity level by 2.9 percent. We also see significant differences in productivity levels across technologies: integrated mills have significantly higher productivity levels -- approximately 10% higher.

Our main focus here is on the interaction between abatement cost and technology. Plants including a pulping process (integrated mills) show a significantly larger impact of abatement costs on productivity than plants without a pulping process. Note that even the first-differenced model, which indicates a relatively small impact of abatement costs on productivity, shows a net effect of abatement costs on productivity of -1.93 for integrated mills (model 2D). In fact, the evidence suggests that virtually all of the estimated relationship between abatement costs and productivity comes from integrated mills, since the PAOC coefficient is no longer significantly negative after the PULP interactions are included (even becoming significantly positive in the first-differenced models).

The predicted impacts of PAOC on productivity for integrated mills are quite large. A one standard deviation increase in PAOC for an integrated mill in the simplest OLS model (2b) is predicted to reduce the plant's productivity by 5.4 percent (-4.51*1.19). The corresponding figures for the first-differenced OLS and GMM models are 2.3 and 4.7 percent, respectively. The estimated impacts of PAOC on non-integrated mills are much smaller, and even turn surprisingly positive in the first-differenced models.

A second way to measure the importance of allowing for differences in impact across plants with different production technologies is to calculate the total impact of pollution abatement costs on productivity at the average plant. For model 2a, this involves multiplying the mean value of PAOC (1.493) times its coefficient (-2.194) for a total impact of 3.3 percent lower productivity levels. For model 2b, we must distinguish between integrated mills and non-integrated mills. The impact of PAOC for integrated mills is larger than for non-integrated mills for two reasons: the mean value of PAOC is higher for integrated mills (2.035 vs. 1.037) and the estimated marginal impact of PAOC is larger for integrated mills (-4.51 vs. -0.751). Therefore the total impact of PAOC on integrated and non-integrated mills is to reduce productivity by 9.2 percent and 0.8 percent respectively. Averaging the total impacts for the two types of plants, weighted by their shares in the population (45.7 percent integrated), we get a total estimated impact on industry productivity of 4.6 percent. This is substantially larger than the 3.3 percent impact estimated without allowing for different impacts. [11]

Table 3 looks at the relationship between plant vintage and productivity. We find that plants born before 1960 are less productive than newer plants -- 10% to 11% less productive. Again, we are more interested in the interaction between OLD and PAOC, which is generally positive across the different specifications, but not significant. The positive coefficient suggests that older plants are less seriously affected, <u>per dollar of abatement costs</u>.[12] When we include PULP and PULP*PAOC (models 3b and 3d), the results for OLD remain fairly similar. The results for PULP and PULP*PAOC are almost identical to those found in Table 2.

We must be careful when interpreting these results, because we cannot distinguish between mismeasured abatement costs and reduced productivity of other inputs. One interpretation of the results is that older plants are grandfathered, and therefore are not required to meet such stiff regulatory standards as newer plants – enough to offset the presumed greater difficulty for older plants in changing their production processes to comply. Another interpretation of the results is that older plants tend to do more of their pollution abatement with

---

[11] The GMM results, in contrast, show relatively little difference between the two impact estimates.

[12] Although older plants have higher mean abatement costs, their smaller coefficients more than outweigh this, and the overall impact of abatement costs (mean*coefficient) is smaller for older plants. As noted earlier, we cannot report the precise numbers due to Census disclosure rules.

end-of-pipe methods (water treatment plants and scrubbers on smokestacks), which are easier to measure. Thus, if newer plants choose to make (or are required to make) more change-in-production-process expenditures, and these expenditures are harder to measure than end-of-pipe ones, we could have a greater mismeasurement of abatement costs in newer plants, leading to a larger (more negative) PAOC coefficient for them.

In Table 4, we add RENOV to the models, identifying those plants which receive large additional investments during the period. Newly-renovated plants show significantly smaller impacts of PAOC on productivity (a positive interaction term) in the OLS models, although this effect goes away in the first-differenced models. To the extent that there is a real difference, it may indicate that newly-renovated plants have fewer problems complying with environmental regulations, or that they are better able to measure their pollution abatement costs. Adding OLD and PULP dummies and interaction terms gives similar results to Tables 2 and 3 -- higher productivity levels for integrated mills, lower productivity levels for older plants, negative interactions for PULP*PAOC, and positive interactions for OLD*PAOC. However, the only consistently significant effect is the PULP*PAOC interaction.

Tables 5-7 present the same sets of analyses, but now instead of using a previously estimated productivity index, we estimate a Cobb-Douglas production function (log-output as a function of log-inputs) along with the technology, vintage, and renovation variables by both OLS and first-differences. The methods give somewhat different results for the contribution of individual inputs. The OLS version (5a) generates coefficients (.69 for materials, .19 for labor, and .12 for capital) that are quite similar to the input cost shares that would be used in growth accounting calculations (.71, .17, and .12 respectively), with estimated returns to scale of 0.994.

The first-differenced results are quite different, with the estimated capital coefficient near zero, and overall returns of scale about 0.92. This supports the finding in past research that it is difficult to identify the positive contribution of capital to output using year-to-year fluctuations in capital within plants.[13] The results for PAOC and its interactions with technology, vintage, and renovation are similar to those found earlier: controlling for the contributions of inputs, output is lower in plants with greater abatement costs, with nearly all of this impact due to integrated mills. The positive interactions of OLD and RENOV with PAOC are more consistently positive than they were in the earlier tables, but are still generally not significant. This reinforces the importance of controlling for differences in production technology (and possibly other plant characteristics) when estimating the impact of environmental regulation on plants in a given industry.

5. Conclusions

The relationship between pollution abatement costs and productivity shows some differences by plant vintage and production technology. We provide evidence that, on average, pulp and paper mills with higher abatement costs have significantly lower productivity levels. We also find that the relationship between abatement costs and lower productivity is almost entirely due to integrated mills, which show a much larger marginal impact than non-pulping mills. Integrated mills also have much higher abatement costs, therefore the predicted impact of regulation on productivity for integrated mills is especially large. For example, a one standard

[13] See Griliches and Mairesse (1995) for a discussion of the effect of fixed-effects estimation on production function estimation.

deviation increase in PAOC for an integrated mill is predicted to reduce the plant's productivity level by 5.4 percent.

Sample calculations of the impact of pollution abatement on productivity show the importance of allowing for differences based on plant technology. In a model incorporating technology interactions we estimate that total pollution abatement costs reduced productivity by an average of 4.6 percent across all the plants. The comparable estimate without technology interactions is 3.3 percent, approximately 30% lower.

Our results for other plant characteristics are not generally statistically significant. We find some differences in productivity level by vintage, with older plants having lower productivity, but being somewhat less sensitive to abatement costs. This may reflect grandfathering of older plants, or differences in abatement methods which make it easier to measure costs in older plants. We also find that plants having recent renovations may be a bit less sensitive to abatement costs, but this effect is generally not significant.

Combining a production function analysis with the technology, vintage, and renovation measures (Tables 5-7), gives similar results to those found earlier. We still find there is a significant negative relationship between abatement costs and output, larger than would have been expected if abatement costs were perfectly measured -- this relationship is once again concentrated almost entirely in integrated mills. Also, older mills, and newly-renovated mills, may be slightly less affected by abatement costs. The production function part of the estimation shows some variation across models, with the coefficients on the OLS-levels model corresponding most closely to the input cost shares (especially for capital, which gets much smaller coefficients in the other models), and to constant returns to scale.

These results have shown the importance of having policy-makers account for the possibility of different impacts of regulation on plants employing different production technologies. As shown above, accounting for differences across plants can substantially affect estimates of the overall economic impact of abatement costs. Our results also suggest that increased regulatory stringency might affect industry structure, if higher abatement costs put integrated mills at a competitive disadvantage. Research seeking to understand why these large differences in impact occur may provide deeper insights into the ways in which environmental regulation affects productivity in the pulp and paper industry.

REFERENCES

Arellano, M., “On the Testing of Correlated Effects with Panel Data,” Journal of Econometrics, 1995, vol. 59, pp. 87-97

Arellano, M. and S. Bond, "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations," Review of Economic Studies, 1991, v. 58, 277-297.

Arellano, M. and O. Bover, “Another Look at Instrumental Variable Estimation of Error-Components Models,” Journal of Econometrics, 1995, vol. 68, pp. 29-51

Barbera, A.J. and V.D. McConnell, "Effects of pollution control on industry productivity: a factor demand approach." Journal of Industrial Economics, December 1986, 161-72.

Bartelsman, E.J. and W.B. Gray, "The NBER Manufacturing Productivity Database," NBER Technical Working Paper 205, October 1996.

Black, S.E. and L.M. Lynch, “How to Compete: The Impact of Workplace Practices and Information Technology on Productivity,” NBER Working Paper 6120, August 1997.

Denison, E.P., Accounting for Slower Economic Growth: The U.S. in the 1970s. Washington: The Brookings Institution, 1979.

Doms, M.E., "Estimating Capital Efficiency Schedules Within Production Functions," Economic Inquiry, January 1996, pp. 78-92.

Gollop, F.M. and M.J. Roberts, "Environmental regulations and productivity growth: the case of fossil-fueled electric power generation," Journal of Political Economy, August 1983, 654-74.

Gray, W.B., "The cost of regulation: OSHA, EPA and the productivity slowdown". American Economic Review, December 1987, 998-1006.

______, "Productivity versus OSHA and EPA Regulations". UMI Research Press, Ann Arbor, MI, 1986.

Gray, W.B. and R.J. Shadbegian, "Pollution Abatement Costs, Regulation, and Plant-Level Productivity," NBER Working Paper 4994, January 1995. Forthcoming 2002 in The Economic Costs and Consequences of Environmental Regulation, W. Gray, ed., Ashgate Publications.

Griliches, Z. and J. Mairesse, "Production Functions: The Search for Identification". NBER Working Paper 5067, March 1995.

REFERENCES (cont.)

Hall, B. and M.L. Kerr, Green Index: A State-by-State Guide to the Nation's Environmental Health. Washington, D.C.: Island Press, 1991.

McGuckin, Robert H. and George A. Pascoe, "The Longitudinal Research Database: status and research possibilities". Survey of Current Business, November 1988.

U.S. Bureau of the Census, "Pollution Abatement Costs and Expenditures", U.S. Govt. Printing Office, Washington, DC, various issues.

TABLE 1

Summary Statistics
(N=1392)

VARIABLE	MEAN	STANDARD DEVIATION	DESCRIPTION
TFP	89.303	22.434	Total Factor Productivity
PAOC	1.493	1.162	Pollution abatement operating costs, divided by plant capacity (2-year peak shipments)
PULP	0.457	0.498	=1 if the plant has pulping facilities
OLD	0.871	0.336	=1 if the plant was opened before 1960
RENOV	0.376	0.485	=1 if the plant had a major renovation project (2-year investment > .8*capital stock) in past 3 years
OUTPUT	10.295	0.807	Log of real output adjusted for inventories
CAPITAL	10.324	1.150	Log of the real capital stock
LABOR	6.776	0.768	Log of production hours
MATERIALS	9.997	0.768	Log of real materials

PULP	= 0	= 1
PAOC	1.037 (0.919)	2.035 (1.190)

TABLE 2

PRODUCTIVITY/TECHNOLOGY MODELS
(dep var = TFP)

	2a	2b	2c	2d	2e	2f
PAOC	-2.194[a] (0.805)	-0.751 (1.564)	-0.881 (0.700)	2.590[a] (0.902)	-2.464[b] (1.160)	2.105[b] (1.076)
PULP		9.463[b] (3.924)				
PULP*PAOC		-3.760[b] (1.831)		-4.578[a] (1.153)		-6.067[a] (1.614)
DYR80	-14.421[a] (1.152)	-14.527[a] (1.191)				
DYR81	-10.741[a] (1.340)	-10.688[a] (1.358)	17.767[a] (1.762)	17.650[a] (1.779)		
DYR82	-1.913 (1.661)	-1.833 (1.671)	22.975[a] (1.733)	22.779[a] (1.748)	4.694[a] (1.628)	4.497[a] (1.624)
DYR83	13.474[a] (1.561)	13.763[a] (1.563)	29.231[a] (1.570)	28.860[a] (1.573)	11.828[a] (1.431)	11.359[a] (1.426)
DYR84	3.434[b] (1.455)	3.537[b] (1.481)	4.460[a] (1.492)	4.464[a] (1.500)	-14.216[a] (1.485)	-14.215[a] (1.502)
DYR85	21.444[a] (2.143)	21.758[a] (2.137)	31.805[a] (1.662)	31.375[a] (1.687)	14.251[a] (1.644)	13.940[a] (1.662)
DYR86	16.618[a] (1.931)	16.792[a] (1.940)	9.520[a] (1.849)	9.379[a] (1.861)	-8.141[a] (1.814)	-8.712[a] (1.807)
DYR87	3.448[c] (2.045)	3.380 (2.073)	1.367 (1.928)	1.351 (1.922)	-17.880[a] (1.920)	-18.105[a] (1.915)
DYR88	-9.717[a] (2.038)	-9.993[a] (2.086)	1.347 (1.604)	1.341 (1.608)	-16.101[a] (1.802)	-16.441[a] (1.802)
DYR89	-17.746[a] (2.253)	-18.044[a] (2.289)	6.247[a] (1.715)	6.157[a] (1.718)	-11.851[a] (1.457)	-11.732[a] (1.462)
DYR90	-20.880[a] (1.984)	-20.976[a] (2.016)	10.831[a] (1.524)	10.610[a] (12.053)	-6.198[a] (1.418)	-6.452[a] (1.426)
RSQUARE	0.341	0.354	0.429	0.433	0.416	0.417
ESTIMATOR	OLS LEVELS	OLS LEVELS	OLS 1-DIFF	OLS 1-DIFF	GMM 1-DIFF	GMM 1-DIFF

(Robust Standard Errors)
All regressions include year dummies
a = significant at the 1% level or better
b = significant at the 5% level or better

TABLE 3

PRODUCTIVITY/VINTAGE MODELS
(dep var = TFP)

	3a	3b	3c	3d	3e	3f
PAOC	-3.546	-1.455	-3.066[c]	1.297	-3.573[b]	2.774
	(2.420)	(3.121)	(1.591)	(1.976)	(1.828)	(2.102)
PULP		8.751[b]				
		(4.030)				
PULP*PAOC		-3.958[b]		-4.379[a]		-6.158[a]
		(1.799)		(1.209)		(1.683)
OLD	-10.752[c]	-9.917				
	(6.243)	(6.740)				
OLD*PAOC	1.867	1.459	2.503	1.308	1.414	-0.621
	(2.524)	(2.755)	(1.771)	(1.858)	(1.843)	(1.929)
RSQUARE	0.358	0.369	0.430	0.433	0.414	0.418
ESTIMATOR	OLS LEVELS	OLS LEVELS	OLS 1-DIFF	OLS 1-DIFF	GMM 1-DIFF	GMM 1-DIFF

(Robust Standard Errors)
All regressions include year dummies
a = significant at the 1% level or better
b = significant at the 5% level or better
c = significant at the 10% level or better

TABLE 4

PRODUCTIVITY/RENOVATION MODELS
(dep var = TFP)

	4a	4b	4c	4d	4e	4f
PAOC	-3.267[a]	-3.141	-0.861	1.782	-2.658[b]	2.902
	(0.810)	(2.883)	(0.813)	(1.931)	(1.279)	(2.217)
PULP		8.050[b]				
		(4.037)				
PULP*PAOC		-2.924[c]		-4.724[a]		-6.246[a]
		(1.765)		(1.164)		(1.745)
OLD		-9.499				
		(6.714)				
OLD*PAOC		1.440		1.338		-0.567
		(2.772)		(1.875)		(1.929)
RENOV	-0.602	-0.145				
	(4.076)	(3.933)				
RENOV*PAOC	2.823[c]	2.457	-0.074	-0.925	0.633	-0.313
	(1.628)	(1.618)	(1.101)	(0.951)	(1.255)	(1.317)
RSQUARE	0.352	0.378	0.429	0.433	0.411	0.418
ESTIMATOR	OLS LEVELS	OLS LEVELS	OLS 1-DIFF	OLS 1-DIFF	GMM 1-DIFF	GMM 1-DIFF

(Robust Standard Errors)
All regressions include year dummies
a = significant at the 1% level or better
b = significant at the 5% level or better
c = significant at the 10% level or better

TABLE 5

PRODUCTION FUNCTION/TECHNOLOGY MODELS
(dep var = OUTPUT)

	5a	5b	5c	5d	5e	5f	5g	5h
CAPITAL	0.120[a]	0.036	0.125[a]	0.108[a]	0.037	0.035	0.034	0.023
	(0.018)	(0.024)	(0.018)	(0.020)	(0.024)	(0.024)	(0.027)	(0.026)
LABOR	0.188[a]	0.173[a]	0.190[a]	0.185[a]	0.174[a]	0.169[a]	0.195[a]	0.174[a]
	(0.036)	(0.055)	(0.036)	(0.035)	(0.055)	(0.054)	(0.063)	(0.064)
MATERIALS	0.686	0.562[a]	0.687[a]	0.699[a]	0.563[a]	0.564[a]	0.549[a]	0.582[a]
	(0.034)	(0.063)	(0.034)	(0.034)	(0.063)	(0.063)	(0.069)	(0.068)
PAOC			-2.329[a]	-0.647	-0.679	3.222[a]	-1.800	3.430[a]
			(0.842)	(1.480)	(0.679)	(0.959)	(1.075)	(1.178)
PULP				11.138[a]				
				(0.392)				
PULP*PAOC				-3.932[b]		-5.139[a]		-6.947[a]
				(1.757)		(1.179)		(1.602)
RSQUARE	0.948	0.561	0.949	0.950	0.561	0.565	0.551	0.555
ESTIMATOR	OLS LEVELS	OLS 1-DIFF	OLS LEVELS	OLS LEVELS	OLS 1-DIFF	OLS 1-DIFF	GMM 1-DIFF	GMM 1-DIFF

(Robust Standard Errors)
All regressions include year dummies
a = significant at the 1% level or better
b = significant at the 5% level or better

TABLE 6

PRODUCTION FUNCTION/VINTAGE MODELS
(dep var = OUTPUT)

	6a	6b	6c	6d	6e	6f
CAPITAL	0.116[a]	0.102[a]	0.037	0.035	0.032	0.022
	(0.019)	(0.020)	(0.024)	(0.024)	(0.027)	(0.027)
LABOR	0.212[a]	0.206[a]	0.172[a]	0.169[a]	0.198[a]	0.185[a]
	(0.036)	(0.036)	(0.055)	(0.054)	(0.063)	(0.063)
MATERIALS	0.681[a]	0.693[a]	0.563[a]	0.564[a]	0.550[a]	0.577[a]
	(0.034)	(0.033)	(0.063)	(0.063)	(0.069)	(0.069)
PAOC	-3.901	-1.230	-2.818[c]	2.130	-3.810[b]	2.921
	(2.481)	(3.081)	(1.667)	(2.019)	(1.728)	(2.119)
PULP		10.152[a]				
		(3.971)				
PULP*PAOC		-4.145[b]		-4.973[a]		-7.027[a]
		(1.745)		(1.216)		(1.776)
OLD	-12.303[c]	-10.991				
	(6.555)	(6.796)				
OLD*PAOC	2.184	1.370	2.450	1.106	2.372	0.643
	(2.574)	(2.739)	(1.836)	(1.888)	(1.800)	(1.866)
RSQUARE	0.951	0.951	0.562	0.566	0.560	0.565
ESTIMATOR	OLS LEVELS	OLS LEVELS	OLS 1-DIFF	OLS 1-DIFF	GMM 1-DIFF	GMM 1-DIFF

(Robust Standard Errors)
All regressions include year dummies
a = significant at the 1% level or better
b = significant at the 5% level or better
c = significant at the 10% level or better

TABLE 7

PRODUCTION FUNCTION/RENOVATION MODELS
(dep var = OUTPUT)

	7a	7b	7c	7d	7e	7f
CAPITAL	0.132[a]	0.108[a]	0.035	0.035	0.029	0.020
	(0.019)	(0.021)	(0.024)	(0.024)	(0.027)	(0.027)
LABOR	0.197[a]	0.211[a]	0.172[a]	0.169[a]	0.181[a]	0.179[a]
	(0.036)	(0.036)	(0.055)	(0.054)	(0.063)	(0.063)
MATERIALS	0.677[a]	0.682[a]	0.562[a]	0.564[a]	0.559[a]	0.580[a]
	(0.035)	(0.035)	(0.063)	(0.063)	(0.069)	(0.069)
PAOC	-3.615[a]	-3.056	-0.961	2.028	-2.346[b]	2.528
	(0.983)	(2.866)	(0.752)	(1.980)	(1.119)	(2.179)
PULP		8.844[b]				
		(4.058)				
PULP*PAOC		-3.035[c]		-4.901[a]		-6.775[a]
		(1.723)		(1.192)		(1.771)
OLD		-10.820				
		(6.771)				
OLD*PAOC		1.498		1.010		0.640
		(2.742)		(1.889)		(1.878)
RENOV	-0.621	-0.002				
	(4.233)	(4.036)				
RENOV*PAOC	3.056[c]	2.366	1.059	0.197	1.792	0.597
	(1.832)	(1.717)	(0.965)	(0.842)	(1.210)	(1.208)
RSQUARE	0.950	0.952	0.562	0.566	0.560	0.565
ESTIMATOR	OLS LEVELS	OLS LEVELS	OLS 1-DIFF	OLS 1-DIFF	GMM 1-DIFF	GMM 1-DIFF

(Robust Standard Errors)
All regressions include year dummies
a = significant at the 1% level or better
b = significant at the 5% level or better